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Cyanobacterial blooms in the Gulf of Gdańsk (southern Baltic): the main effect of eutrophication

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Abstract

The most striking aspect of eutrophication in the Baltic are the summer blooms of cyanobacteria. Some of the blooms are toxic to marine organisms and poisonous to people. Our studies, conducted over the last three decades, report on mass occurrences of *Aphanizomenon flos-aquae* (L.) Ralphs and *Nodularia spumigena* Mertens. It is generally assumed that cyanobacterial blooms in the Baltic Sea are stimulated by the low ratio of N:P and initiated by high water temperatures. The mean annual value of this ratio in the Gulf of Gdańsk, since 1981, is 7:1-8:1, with the lowest values, of about 4, being seen in July when the cyanobacterial blooms begin. During three years of observations (1992-1994) the smallest number of recorded taxa was reported in 1993, concurrent with the lowest water temperature (16°C in summer). In August 1994, when the temperature increased to 22°C, a huge bloom was seen. *Nodularia spumigena* was very abundant in that bloom, and nodularin concentration of 2.59 mg toxin per g dry weight of bloom sample was recorded. A similar situation has also been observed in the years 2003-2006.

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INTRODUCTION – THE ECOLOGY OF THE BALTIC SEA

The Baltic Sea, which has an area of 385 000 km^2, comprises just 0.1% of the word's oceans. Nevertheless, it is unique due to many of its features, and is the largest body of brackish water in the world. From a hydrological point of view, the Baltic resembles a lake in many ways, resulting in interesting flora and fauna, which are well adapted to the brackish aquatic environment. The current biocoenosis composition has been influenced by numerous factors. During the last European glacial age the Baltic was alternately a huge marine bay and a large, freshwater lake, resulting in the development and succession of several ecosystems therein. Currently marine influences come from North Sea water inflows, which greatly affect the salinity of the deep water. The freshwater influence comes from fluvial waters which impart the surface layer with a lower salinity (Voipio 1981).

The salinity in the Baltic varies greatly, from 2-4 PSU in the Gulf of Bothnia, 7-13 PSU in the central Baltic, 15-30 PSU at the surface to 32-34 PSU at the bottom of Kattegat waters, and 20-30 PSU at the surface to 32-35 PSU at the bottom of Skagerrak waters. The water column is stratified by the halocline at a depth of 60-80 m in the central Baltic and at 10-20 m in the Kattegat and the eastern Skagerrak. In the summer there is also a thermocline. The salinity gradient influences the composition of biological communities. Although a few marine species occur in the Baltic Sea, their numbers decrease towards the northeastern part of the Baltic and the Bothnian Sea (Jansson 1972, Łomniewski et al. 1975).

Disturbances to the Baltic environment occurred in the 1960s when significant declines in oxygen concentrations were seen in the bottom waters of several deep basins. Increasing concentrations of nutrients had already been observed in these deep waters. Since that time additional signs of eutrophication have been observed. The first obvious effects of eutrophication in the Baltic were noted in the mid 1970s when filamentous algae were washed ashore in large quantities. In 1980 and 1981 fish mortalities due to oxygen deficiency were reported by fishermen, and in recent years toxic algal blooms have been observed in different areas of the Baltic (Pliński 1989, 1990).

This paper examines the importance of phosphorus inputs and N:P ratios as factors responsible for cyanobacterial blooms in the Gulf of Gdańsk, a part of the Southern Baltic.

CHANGES IN NUTRIENT CONCENTRATIONS IN THE GULF OF GDAŃSK

The term 'nutrient' refers to any inorganic (mineral) substance that can be assimilated by photo-autotrophic organisms in order to promote growth. In addition to macro-nutrients, such as carbon, nitrogen, phosphorus, and silica (diatoms only), there are also micro-nutrients, such as iron and manganese, which are required in only very small amounts to sustain growth. These nutrients are regenerated by the mineralization of organic matter. The total sum of nutrients in natural waters combined with dissolved and particulate organic matter can be used as a standard for determining the stages of the eutrophication process.

Caused by mineral input from erosion, eutrophication is an ongoing natural process that lasts for many years. However, in recent years it has been observed to accelerate in many water bodies, and advanced eutrophication is there seen to be the result of human activity. Eutrophication processes affect the physico-chemical conditions of water and may subsequently be reflected at various trophic levels in the ecosystem (Pliński and Jóźwiak 1996).

Throughout the twentieth century, evident increases in the input of nutrients to the Baltic Sea have been noted. At the beginning of the century, this input was estimated at 10,000 tons of phosphorus and 300,000 tons of nitrogen annually. A significant rise was noted after the 1950s, but a dramatic increase was not apparent until the end of the 1970s (Elmgren 1989). The load increased in the 1980s to approximately 80,000 tons and 1,200,000 tons, respectively (Larsson et al. 1985). Primary production in most areas in the Baltic Sea has also increased since the 1970s. During this period, chlorophyll concentrations have increased by half and primary production doubled in the southern Baltic Sea (Leppäkoski and Mihnea 1996).

The fertility of the Polish Baltic Sea coastal zone in the 1979-1983 period was characterized by high levels of the mean concentrations of essential nutrients. These concentrations underwent strong seasonal fluctuations connected with the periodicity of primary production and in the discharge of nitrogen, phosphorus, and silicon compounds from rivers (Elmgren 1989).

Seasonal fluctuations of nutrient concentrations occur in the Gulf of Gdańsk in a two-phase cycle. The productive season extends from April to September and is expressed by low concentrations of nitrates and phosphates in the euphotic layer. Despite high primary production during the 1970s, 100 percent of the nutrients in the euphotic layer of the Gulf of Gdańsk were not utilized. In subsequent years nutrients were observed to persist in surface waters in the spring-summer season and although mainly nitrates were seen, more recently surplus phosphates have also been recorded. Analysis of long-term variations in the fertility of the Gulf of Gdańsk has shown that statistically significant accumulation of phosphates and nitrates occurs below the halocline in this basin, with an annual trend coefficient of 0.03 µmol PO_4 dm^{-3} and 0.24 µmol NO_3 dm^{-3} at a depth of 80 m. Similar trends expressed by annual coefficients of 0.015 µmol PO_4 dm^{-3} and 0.35 µmol NO_3 dm^{-3} were determined in the homogenous layer of the winter surface waters. These indicate the progressive eutrophication of the Gulf of Gdańsk (Trzosińska et al. 1989).

The Gulf of Gdańsk region of the Baltic Sea is exposed to severe environmental degradation, which is undoubtedly caused by eutrophication and an overall increase in pollution. In this region the impact of anthropogenic factors is particularly strong and multifaceted. The large urban and industrial agglomeration of the Tri-Cities of Gdańsk, Sopot, and Gdynia, and many ports, are located on the Gulf of Gdańsk. Poland's largest river, the Vistula, flows into the gulf carrying heavy pollution loads from its extensive and highly developed catchment area (Pliński and Wiktor 1987, Wiktor and Pliński 1992). The region is thus under strong eutrophic stress. The analysis of long-term, mean values of inorganic nitrogen and phosphorous clearly indicate that their concentrations in Gulf of Gdańsk waters increased at the beginning of the 1970s. In subsequent years the levels of nitrogen have remained at more or less similar levels, with a slight tendency to decline, while levels of phosphorous again increased significantly in the late 1980s and early 1990s (Łysiak-Pastuszak 2004). This is reflected in the N:P values, which were lowest at 4.5 in 1986-91, and at 7.7 for the decade from 1995 to 2004 (Table 1). The mean annual values of nitrate and phosphates have also dropped since this time, and thus it can be stated that the eutrophication of the Gulf of Gdańsk has exhibited a declining trend since 2005.

Table 1

Mean values of nitrogen (as NO_3) and phosphorous (as PO_4) in µmol dm^{-3} and N:P ratios in water from the Gulf of Gdańsk during various time periods.

Year	N(NO_3)	P(PO_4)	N:P
1979-83 (Trzosińska et al. 1989)	4.54 ±7.66	0.46 ±0.46	9.8
1986-91 (Falkowska et al. 1993)	3.95 ±2.86	0.86 ±1.38	4.5
1995-04 (Lysiak-Pastuszak 2005)	3.7	0.48	7.7

TRENDS IN PHYTOPLANKTON DEVELOPMENT

The phytoplankton of the Gulf of Gdańsk have been the subject of study for many years (Pliński 1975, 1995; Pliński and Picińska 1986; Pliński and Witek 1998). The main components of this phytoplankton are diatoms, cyanobacteria and green algae, with the first two groups playing the principle role in terms of abundance and biomass. The abundances of green algae are low, and they never form blooms, while in recent years the blue-green algae have become increasingly important. The analysis of phytoplankton development in the Gulf of Gdansk over the last fifty years indicate that there has been a trend for the overall abundance to increase (relative biomass), with changes in the dominant species also apparent. The 1980s were characterized by the domination of diatoms, while in the 1990s the dominant group became cyanobacteria (Fig. 1). This latter period is when the lowest N:P ratio was recorded (Table 1), and there was a relative deficit in nitrate concentrations. The excess of phosphorous could have been utilized by cyanobacteria, which are capable of binding atmospheric nitrogen. Drastic disruption in the balance of the N:P ratio, which was 16:1, could have contributed to the intensified development of cyanobacteria, which, under advantageous thermal conditions, have produced vast blooms since the mid 1990s (Fig. 1).

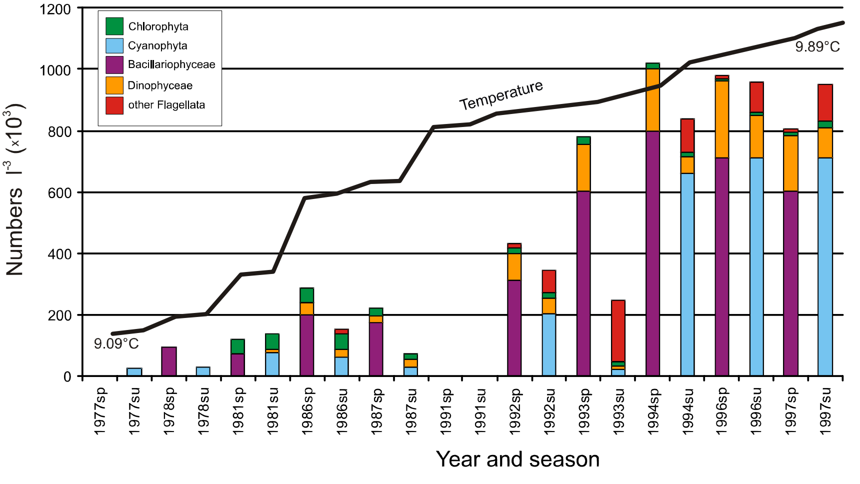

Fig. 1. Long-term means of phytoplankton population numbers in the Gulf of Gdansk and changes in temperature during the 1977 – 1997 period (sp – spring, su – summer) (no bars means no data).

Distinct fluctuations in the intensity of blooms have been observed from year to year. Although it is difficult to determine the precise cause of this, it is thought that the N:P ratio plays an important role. This hypothesis is confirmed by comparing the intensity of cyanobacterial blooms, measured by nodularin concentration (produced by *Nodularia spumigena*), with fluctuations in the N:P ratio during the 2001-2005 period (Fig. 2). The lowest nodularin values were recorded in 2002, concurrent with the highest N:P ratio value of the analyzed period.

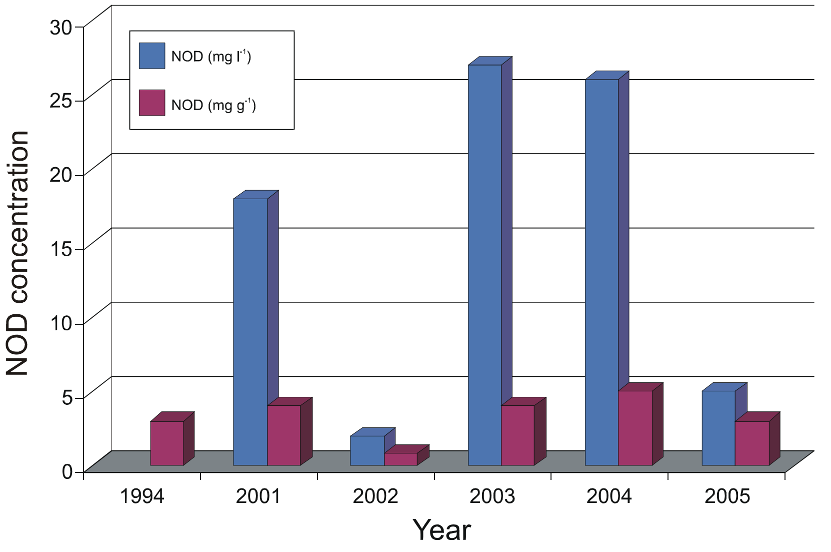

Fig. 2. Maximum concentrations of cell-bound nodularin (NOD) in water (blue) and freeze-dried phytoplankton samples (purple) measured during the most intensive blooms of *Nodularia spumigena* in 1994-2005 (after Mazur-Marzec at al. 2006) and mean N:P ratio (after Łysiak-Pastuszak pers. com.).

CONCLUSIONS

The case study presented here, i.e., the eutrophication of the Gulf of Gdańsk, indicates that it is not only increases in nutrient concentrations that cause cyanobacterial blooms.

Nevertheless, the current comparative study confirms that one of the significant contributing factors leading to blooms in eutrophic waters are distortions in the nutrient balance. Certainly, an excess of phosphates supports intensified cyanobacteria blooms. Thus, a low N:P ratio is considered to be one of the most important parameters responsible for an increase in the intensity of cyanobacteria blooms. Apart from these two essential nutrients, and especially phosphorous which stimulates the growth of nitrogen-fixing cyanobacteria, a high demand for iron and molybdenum are important (Stal et al. 2003). These elements are components of nitrogenase, the enzyme catalyzing nitrogen fixation in cyanobacteria, while iron is also a component of ferredoxin, which plays the role of electron donor to nitrogenase. Intense growth of cyanobacteria is also stimulated by high irradiance, calm weather, rising surface water temperature, and distinct thermal stratification (Mazur-Marzec et al. 2006).

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